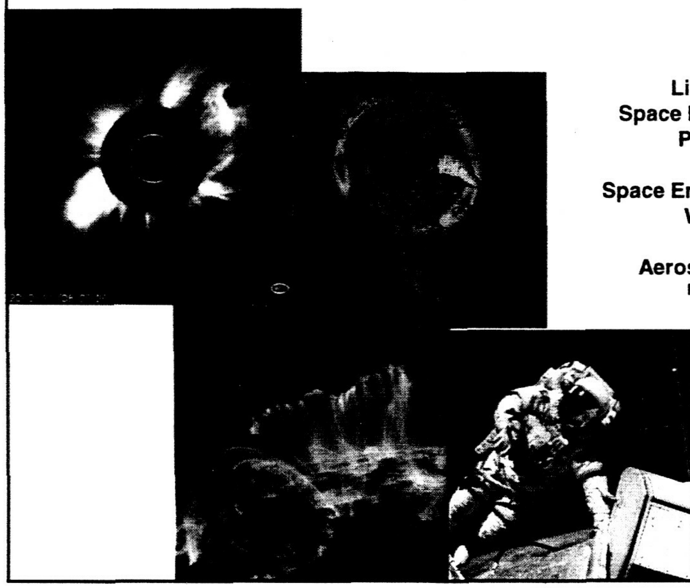
Living With a Star Program

Develop the scientific understanding necessary to effectively address those aspects of the connected Sun-Earth system that directly affect life and society.

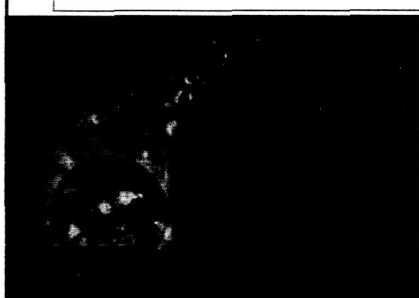


Janet Barth
Living With a Star
Space Environment Testbed
Project Scientist

Space Environment and Effects
Working Group

Aerospace, Los Angeles
November 2-4, 2004

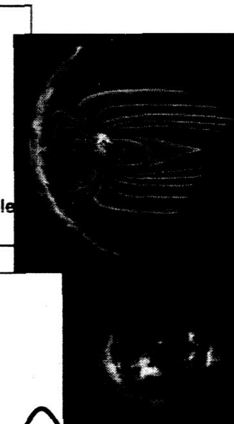
Sun-Earth as a Connected System

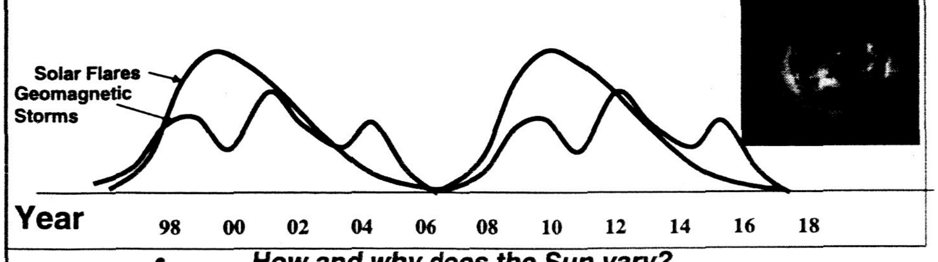


Varying

- **Radiation**
- **Solar Wind**
- **Energetic Particles**

Driven by 11 Year Solar Cycle



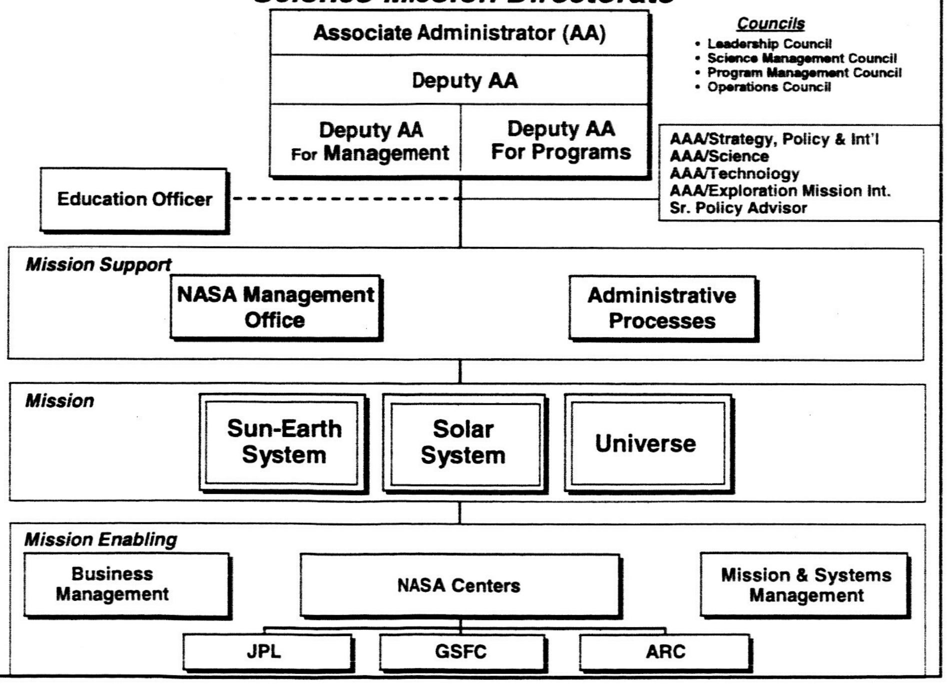


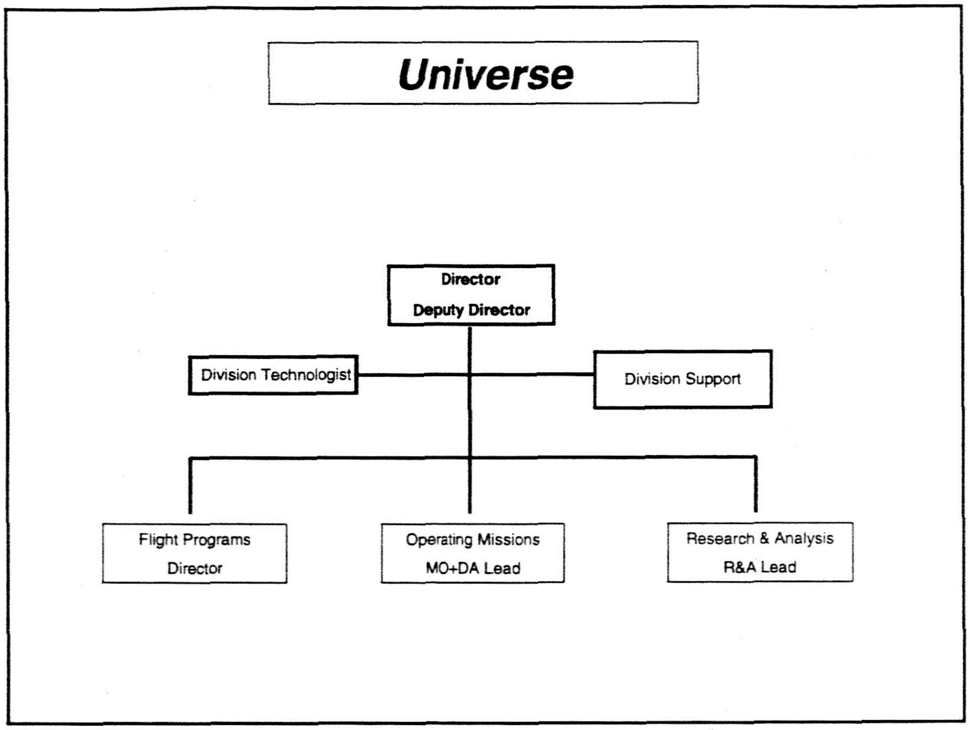
- ***How and why does the Sun vary?***
- ***How does the Earth respond?***
- ***What are the impacts on life and society?***

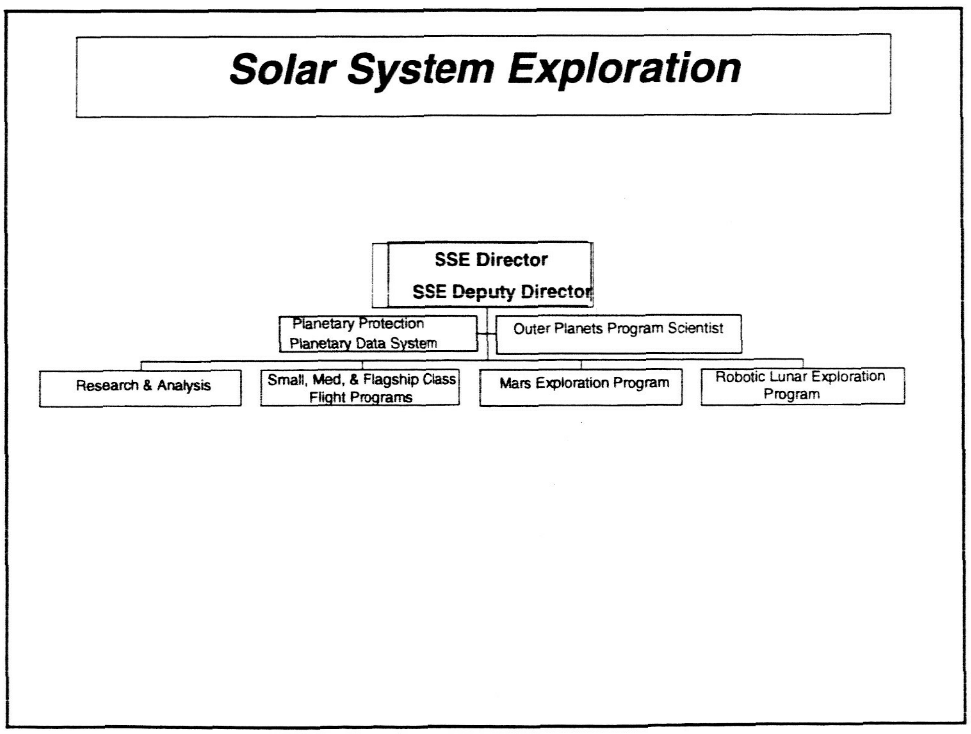
The Vision for Exploration: Moon, Mars and Beyond...

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond
- Extend human presence across the solar system, starting with human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations (enables)
- Develop the innovative technologies, knowledge, and infrastructure both to explore and support decisions about the destinations for human exploration
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests

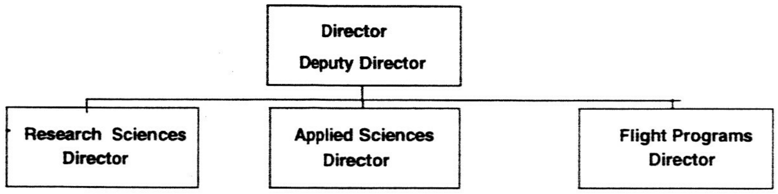
Science Mission Directorate



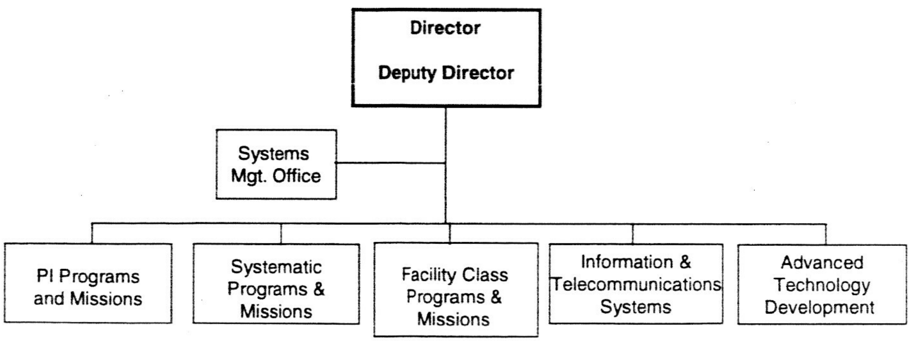

Universe
Director
Deputy Director
Division Technologist
Division Support
Flight Programs
Director
Operating Missions
MO+DA Lead
Research & Analysis
R&A Lead


Solar System Exploration
SSE Director
SSE Deputy Director
Planetary Protection
Planetary Data System
Outer Planets Program Scientist
Research & Analysis
Small, Med, & Flagship Class
Flight Programs
Mars Exploration Program
Robotic Lunar Exploration
Program

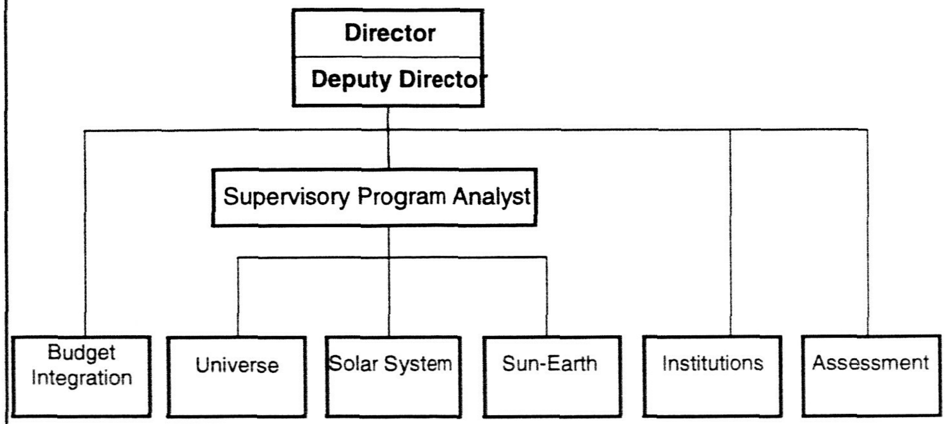
Sun Earth System



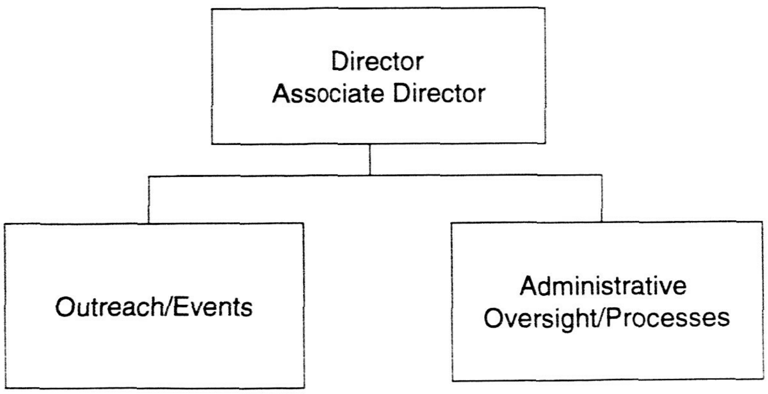
Mission & Systems Management



Business Management



Administrative Processes



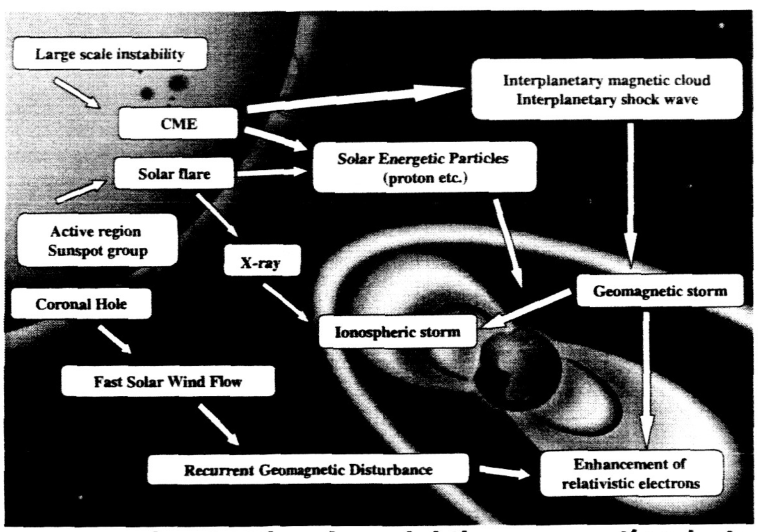
NASA Management Office - JPL

Director
Deputy Director

Contracts Management

Administrative Oversight

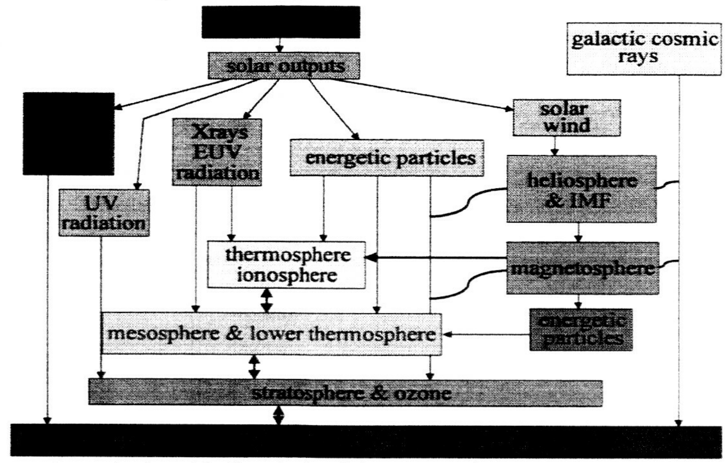
LWS Connectivity



Discover, understand and model the <u>connection</u> between solar phenomena and geospace disturbances.

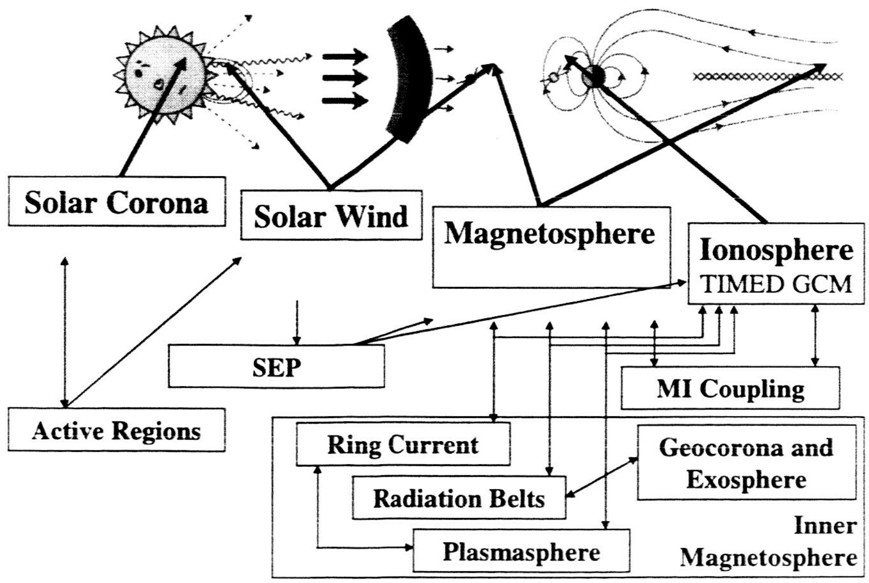
LWS is a Systems Approach

LWS focuses not on any one region of space, but rather on our Sun Earth Region as one system.



A very important part is the study of the connection between the regions and how one drives a response in another.

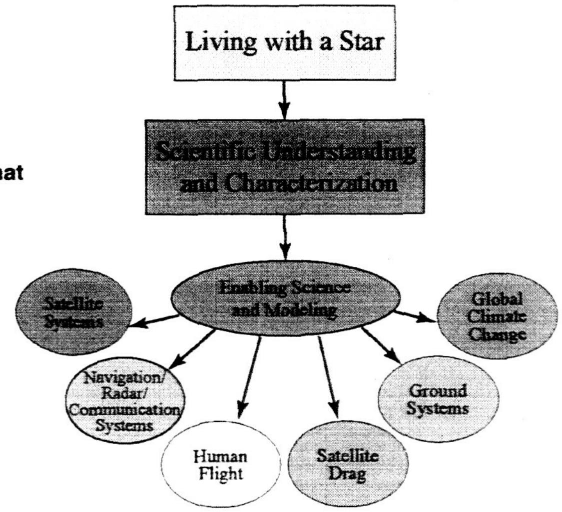
An Example of Space Weather Modeling



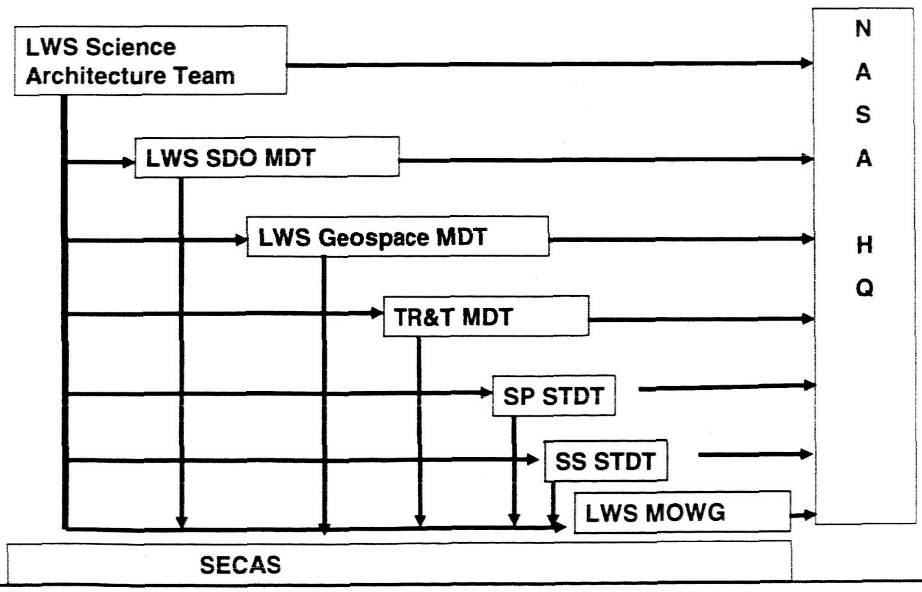
Science Application as the Focus

The primary goal of the LWS Program is to develop the understanding necessary to enable the U.S. to effectively address those aspects of the Connected Sun-Earth system that directly affect life and society.

- Space Weather
- Sun-Climate Connection



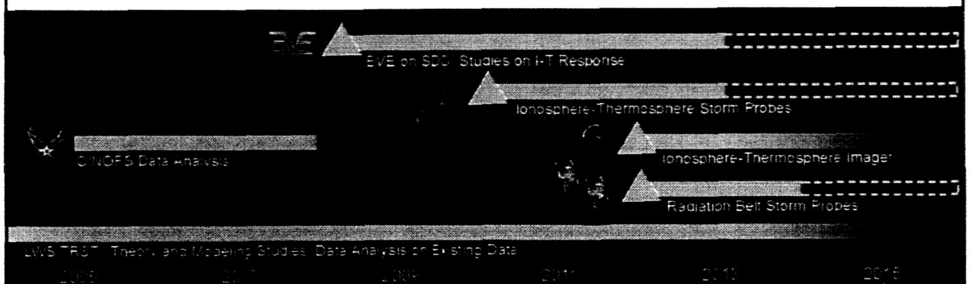
LWS Science Planning



LWS: ***Develop the scientific understanding necessary to effectively address those aspects of the connected Sun-Earth system that directly affect life and society.***

- ***Solar Dynamics Observatory***
  SDO Mission and LWS program was confirmed in June, 2004.
- ***Geospace Missions***
  AO while delayed in near-term is in the process of being developed.
- ***Sentinels***
- **Strategy panel report is out. Definition team to started.**
  A task group was formed to look at agency's need for prediction of radiation environment/space climate chaired by Golightly (report due in Fall, 2004).
- ***Solar Probe Mission***
  Science Technology and Definition Team kick-off meeting took place on March 3-4, 2004, 2nd meeting on July 6-7, 2004 and 3rd meeting 23-24 Sept.
- ***Space Environment Testbeds***
  Looking for partners to ride. Early results from data mining effort are already in use by JWST engineers.
- ***Targeted Research & Technology Program***
  TR&T Steering Committee formed. TR&T goals and priorities set by SC. (Report out in Spring of 2004). Sun climate task group report released during Fall AGU. FY05 proposals due on 10th Sept., 2004.
- ***Partnership at National and International Level***
  Being pursued

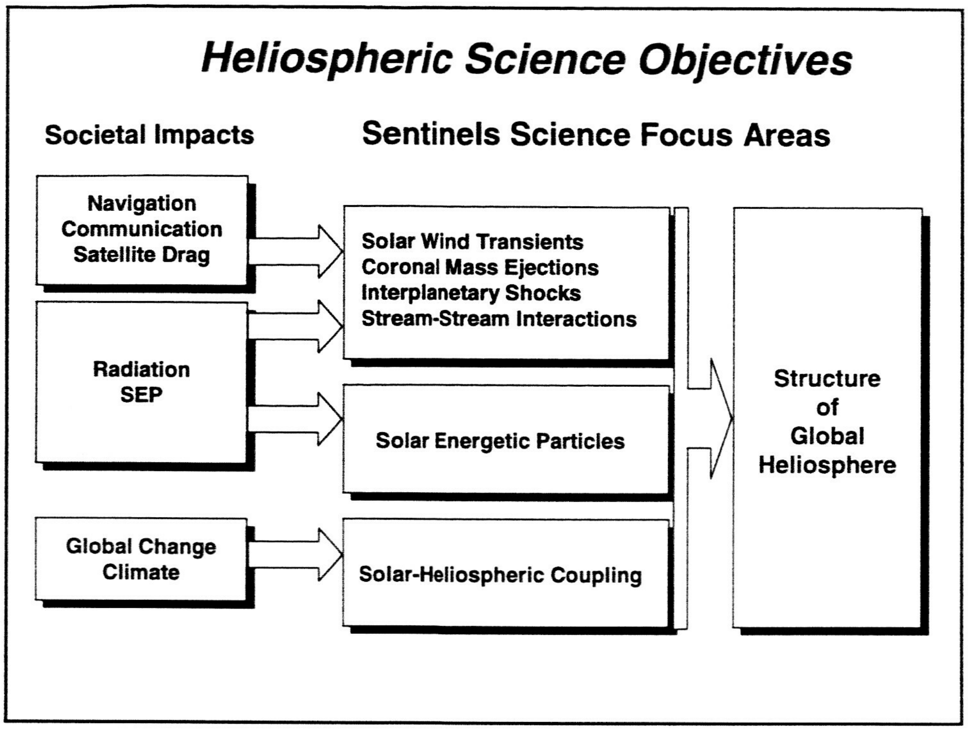
Geospace Missions Status

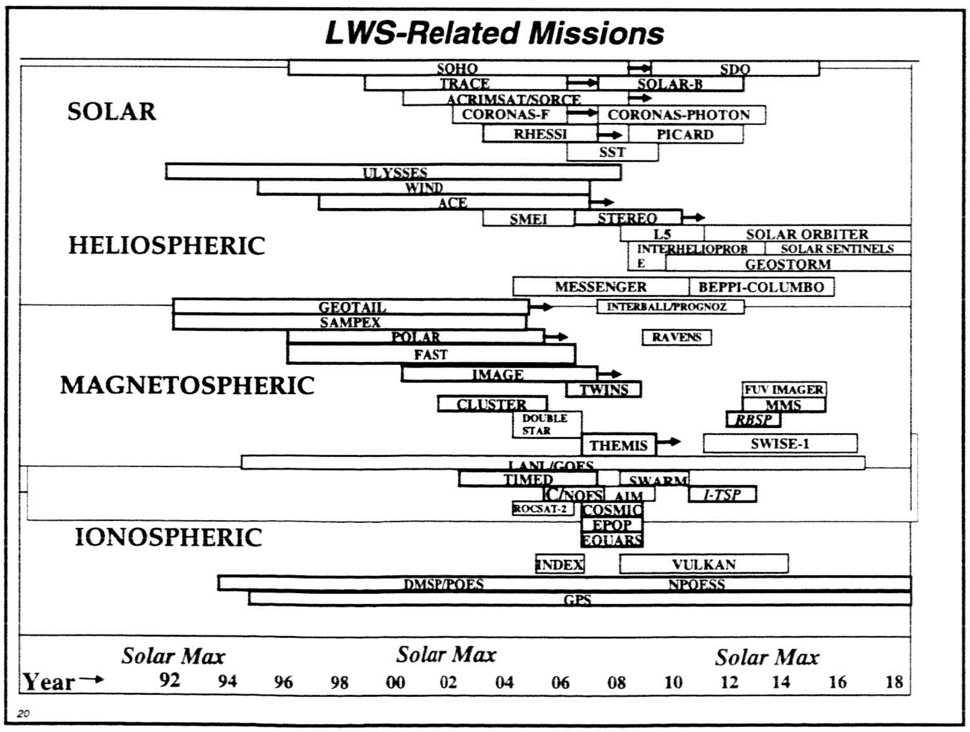


The status of the LWS/Geospace Missions remains as follows:

- **We are presently in pre-formulation for the Geospace Core Missions (2-IT, 2-RB and an ionosphere-thermosphere imager (FUV) on a Mission of Opportunity).**
- **The Program office and Headquarters will continue to seek partners (both national and international) in order to reduce cost as well as advance the schedule.**

Announcements of Opportunity are in preparation that reflect the above strategy.


Heliospheric Science Objectives
Societal Impacts
Sentinels Science Focus Areas
Navigation
Communication
Satellite Drag
Radiation
SEP
Global Change
Climate
Solar Wind Transients
Coronal Mass Ejections
Interplanetary Shocks
Stream-Stream Interactions
Solar Energetic Particles
Solar-Heliospheric Coupling
Structure
of
Global
Heliosphere


LWS-Related Missions
SOLAR
SOHO
SDO
TRACE
SOLAR-B
ACRIMSAT/SORCE
CORONAS-F
CORONAS-PHOTON
RHESSI
PICARD
SST
HELIOSPHERIC
ULYSSES
WIND
ACE
SMEI
STEREO
L5
SOLAR ORBITER
INTERHELIOPROBE
SOLAR SENTINELS
GEOSTORM
MESSENGER
BEPPI-COLUMBO
MAGNETOSPHERIC
GEOTAIL
SAMPEX
INTERBALL/PROGNOZ
POLAR
RAVENS
FAST
IMAGE
TWINS
FUV IMAGER
MMS
RBSP
CLUSTER
DOUBLE STAR
THEMIS
SWISE-1
IONOSPHERIC
LANL/GOES
TIMED
SWARM
C/NOFS
AIM
I-TSP
ROCSAT-2
COSMIC
EPOP
EQUARS
INDEX
VULKAN
DMSP/POES
NPOESS
GPS
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Solar Max
Solar Max
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LWS & Exploration (Geospace)

Radiation effects will be a significant part of any space exploration program. There are three main areas where I see LWS geospace might contribute

Manned space flight

The biggest risk is in interplanetary space (or Lunar surface) from SEPs (Solar energetic particles)

There is also significant risk from the terrestrial radiation belts during travel to the moon or Mars and on the international space station or similar facility if moon and Mars missions are staged and starts with a stay in LEO

Planetary exploration

If we want to understand the radiation environments at other planets and

predict the potential effects there then we need to use the Earth's radiation belts as a local laboratory. Among the questions are:

What do we expect at other planets?

How do we scale what we observe if we don't understand the dynamics

Space Infrastructure

Understanding the impacts of the Earth's radiation environment on space infrastructure will be increasingly important as mankind moves even more aggressively into space.

Space infrastructure will have to increase and will be vulnerable to radiation belt effects

Space exploration is not completely uncoupled from the increasing DOD programs in Military Space, Space Control, and Space Situational Awareness. LWS geospace has increasing relevance to those increasingly important national programs.

LWS & Exploration (cont.)

1) Near-term: e.g. assets which can be readily adapted to fit more of NASA's space weather needs. Missions currently taking measurements (SOHO, ACE, Ulysses), missions which can be mobilized for space weather usage with minimal effort (Cassini and other planetary programs), models which can be easily implemented, and modifying observing and reporting structures to suit the broader needs of NASA.
2) Intermediate term: e.g. focus on technology development, such as radiation-hard components, which will allow us more independence and reliability in space; focus on gathering more information regarding the exposure and effects of exposure of various types of radiation on humans.
3) Long-term: e.g. identifying current plans and roadmaps which can be synergized to better suit NASA's needs.

Earth's Radiation Belts (1)

- Problem addressed: Transits of moon and Mars bound vehicles through the radiation belts
  - Contributes to radiation exposure to astronauts (?)
  - Affects the reliability of hardware
- Impact if not addressed: Large safety margins are used to account for the uncertainty in the particle energy spectra predictions which translate to increased mass.
- Current capability: Design models of the Earth's radiation belts (AE-8 and AP-8) predict the trapped radiation environment over long-term averages (several years).
  - The models do not have worst case information or directionality.
  - The models do not have error bars or statistical information.
- Required capability: Models of the radiation belts that –
  - Include dependence on solar activity parameters
  - Take advantage of recent progress in understanding particle loss and acceleration processes and the effects of solar storms.
- Assets:
  - Prototype models – TPM-1 (TIROS, CRRES), POLE (LANL)
  - Data - SAMPEX, POLAR, LANL s/c, ICO, CRRES, TIROS, ESA S-REM monitors

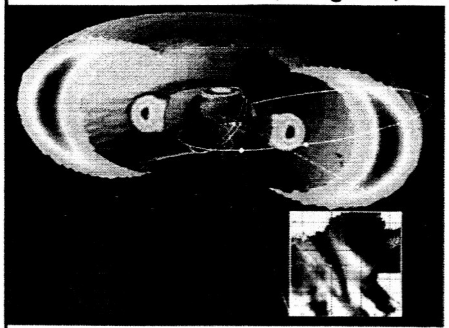
Earth's Radiation Belts (2)

- Question: Are forecasts of radiation belt particles levels required for astronaut protection?

The LWS Geospace Program

Science:

- **Acceleration, global distribution, and variability of the radiation belt particles that produce harsh environments for spacecraft and humans**
- **Mid-latitude ionospheric variability and irregularities that affect communications, navigation, and radar systems**



Core Investigations:

RBSP/Radiation Belt Storm Probes (2012)

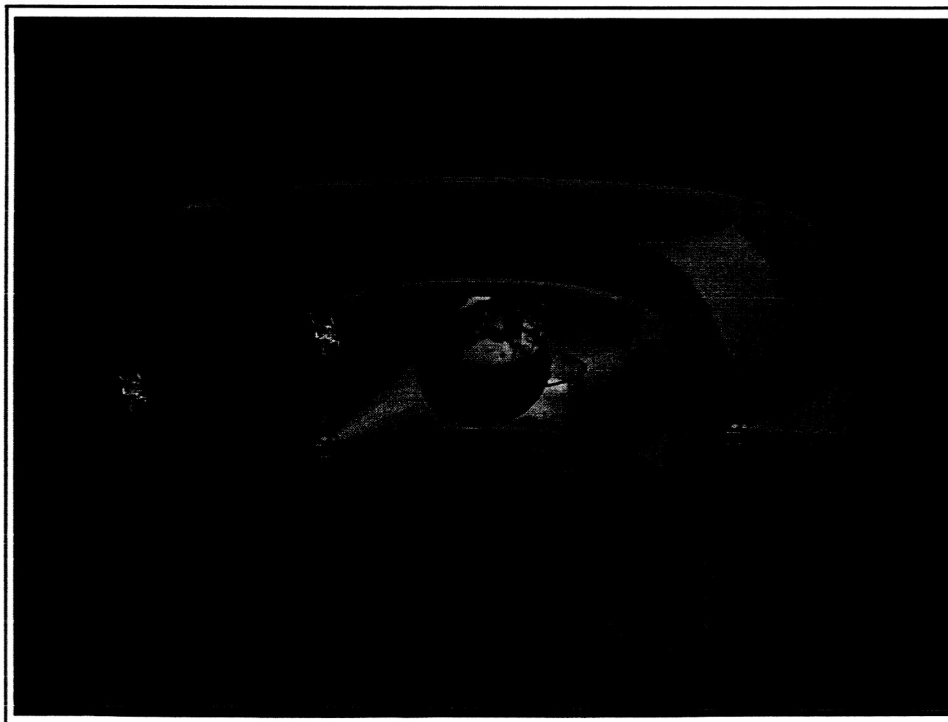
- **Two spacecraft, nearly identical, low-inclination elliptical (500 km x 5.5 R_E) orbits**
- **First spacecraft fully instrumented),second with subset of instruments**
- **Radiation belt electrons, magnetic field, ring current particles, AC magnetic fields, DC/AC electric fields**

ITSP/Ionosphere-Thermosphere Storm Probes (2010)

- **Two spacecraft in nearly identical, 60°inclination, circular orbits at a nominal altitude of 450 km**
- **Both spacecraft identically instrumented**
- **DC electric fields (ion drifts), neutral wind vector, plasma density/fluctuations, plasma density altitude profile, scintillations, neutral density/composition/temperature**

Measurement Strategy:

Concurrent observations by RBSP, ITSP, and the SDO EUV imager, with global mid-latitude UV imaging on mission of opportunity.



Geospace Science Priorities

1: Acceleration, global distribution, and variability of energetic electrons and ions in the inner magnetosphere.

2A: Global-scale behavior of the ionospheric electron density.

2B: Small scale ionospheric density irregularities

3A: Improved specification of the neutral density in the thermosphere.

3B: Distribution of electric currents connecting the magnetosphere to the ionosphere.

4: Relationship between very energetic electron and ion fluxes in the interplanetary medium and their fluxes at low altitude

5: Geospace drivers that potentially affect ozone and climate.

Radiation Belts: Top Priority for Geospace

Radiation Belt Priority Observables

Priority Objective: Characterize and understand the acceleration, global distribution, and variability of the radiation belt electrons and ions that produce harsh environments for spacecraft and humans.

Which physical processes produce radiation belt enhancements?

- Direct convection
- Explosive inductive electric fields
- ULF waves and classical diffusion
- Interplanetary shocks.
- Local, invariant-violating acceleration processes

Measurements:

- Simultaneous particle intensities at various radial distant separations
- Simultaneous multi-point phase space densities (full pitch angles and B)
- Global convection/transient E, and E and B waves
- Simultaneous multipoint B for characterizing dynamic configuration
- Ring current ion composition and intensity

Radiation Belt Priority Observables

What are the dominant mechanisms for relativistic electron loss?

- Magnetopause shadowing.
- Current sheet scattering
- Plasma Wave scattering
- Coulomb scattering

Measurements:

- Electron pitch angle distributions near loss cone
- Low-altitude electron precipitation losses and compare with equator
- Power spectral intensity of relevant plasma waves

What role does the ring current play in radiation belt creation and loss?

- Time history, locus, composition, and energy of ring current ions
- Role of ring current in storm-time waves affecting radiation particles
- Role of the ring current on global electric and magnetic fields that cause radiation belt transport.

Measurements:

- In-situ ring current ion composition, pressure gradients
- Global distribution and evolution of ring current ion composition, energy density and pressure gradients

Implementation Radiation Belt Storm Probes

Description: Two spacecraft in near equatorial, elliptical orbits (~500 km x 4.5 R_E altitude)

Mission Life: 2 years with optional 3-yr extension

Launch Date: 2010

Space Access: One launch on Medium Class ELV

Measurements,:

- 20 keV - 20 MeV electrons
- B and ULF waves
- DC E-field
- B and E VLF waves
- ring current ions (20-600keV), composition
- plus, if feasible,
  - energetic protons (1-200 MeV)
  - 0.01 – 20 keV ions and electrons

plus, if feasible:

- ENA ring current imager on appropriate polar, high altitude, spacecraft
- and, on platform in LEO orbit,
  - precipitating energetic electrons (20 keV – 20 MeV)
  - proton monitor (1-200 MeV)

Targeted Research and Technology Program (TR&T)

- 1. Focused research program. Results available on dedicated WWW site (lws-trt.gsfc.nasa.gov). Examples follow.
- 2. Sponsors workshops like the Radiation Belt Workshop on October 5-8, 2004.
- 3. Long term goal: End-to-End (Sun-to-Mud) models. Short term goals set by steering committee with rotating membership.
- 4. Resource for those seeking to transition results to operations-welcome contacts with and input from the user community.

RB Objective in Current Round of TR&T Proposals

- Determine the mechanisms responsible for the formation and loss of new radiation belts in the slot region in response to geo-effective solar wind structures.
- Proposals under review - research teams will be formed after selection.

International Living With a Star (ILWS): Seeking Synergies

- **ORBITALS (Outer radiation belt injection, transport acceleration and loss satellite).**

  A small satellite proposed as a Canadian mission contribution to the ILWS program. ORBITALS is an inner magnetosphere mission which targets the dynamics of the radiation belts, plasmasphere and ring current. The ORBITALS is currently undergoing a Canadian Space Agency (CSA) funded Concept Study, which will be completed by March 31st 2005. PI is Dr. Ian Mann (Physics Dept., U. Alberta).

International Living With a Star (ILWS): Seeking Synergies

- **SWISE (Space Winds and Storm Exploration) Program (PRC)**

  Three spacecraft in 65° inclination, simultaneous launch:

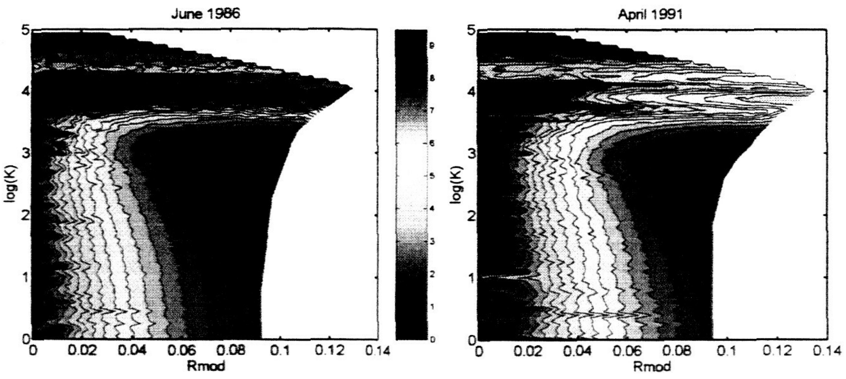
  SWISE-1 (IT, 300-700 km)

  SWISE-2 (RB, 700 km - 7.5 R_E)

  SWISE-3 (Solar Wind, 2- 22 R_E)

  Phase A report to be finished in 2005.

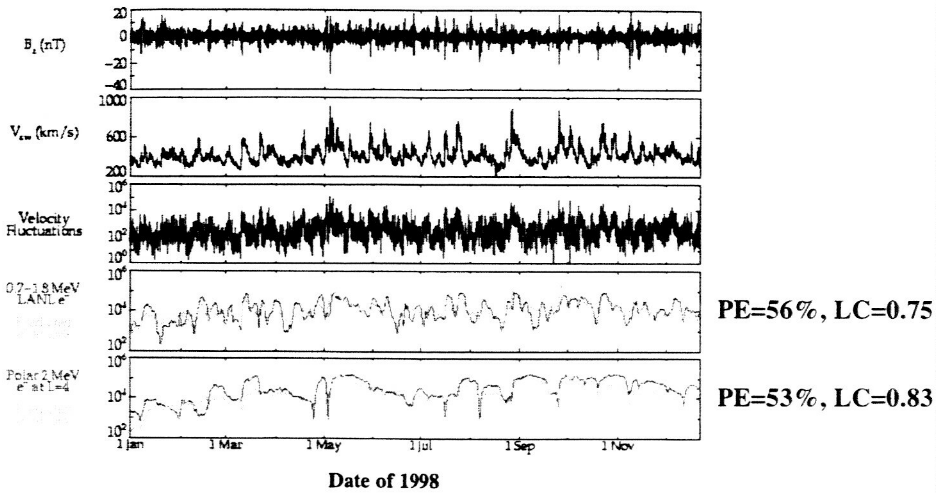
Modeling the Long-Term Variations of Energetic Trapped Protons (S. Huston, PI)



Modeling the Long-Term Variations of Energetic Trapped Protons

- The previous figure shows contours of constant proton flux (> 80 MeV) measured by the POES satellites at 800 km altitude, at two points in the solar cycle: June 1986 (solar minimum) and April 1991 (solar maximum). Note that protons move to lower values of R_{mod} (i.e., closer to Earth) at solar minimum. Also note the appearance of strong secondary belts at log(K) ~ 3.8 and 4.2 in the April 1991 data.
- The K, R_{mod} coordinate system used has the advantage that it is based on adiabatic invariants, and thus accounts for secular changes in the Earth's magnetic fields.
- The POES data are being gridded and smoothed and will be combined with similar data from CRRES and SAMPEX (SAMPEX data are being processed by BIRA in Belgium).
- The resulting data base will extend from energies of approximately 1 MeV to over 300 MeV and will permit the development of improved specification models of the trapped proton environment.
- Once the different data sets are combined as described above, we plan to use physics-based models to extrapolate the low-altitude, high energy data to higher altitudes, thus providing a specification model into the heart of the inner zone.

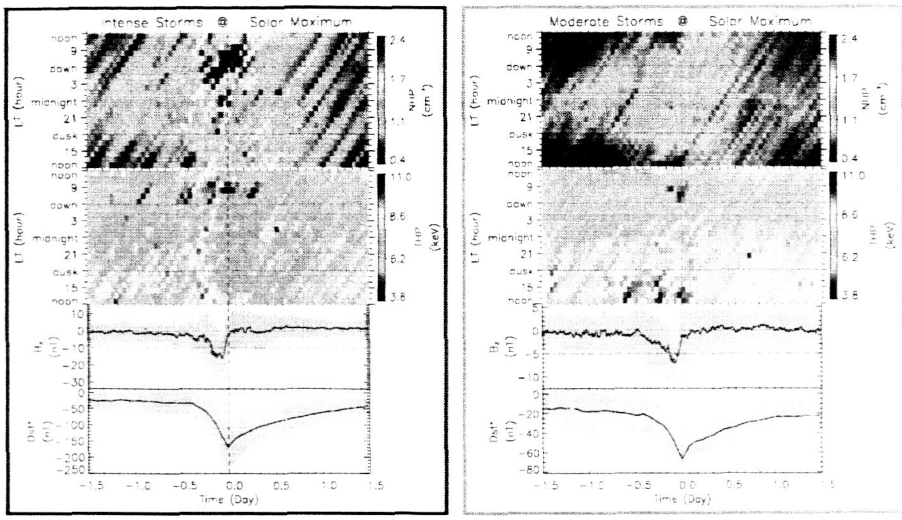
Prediction of Outer Radiation Belt Electrons Based on Solar Wind Measurements (PI Li)



Science Nugget from NAG5-10850: *Superposed Epoch Analysis of Ring Current Geoeffectiveness*

PI: Michael Liemohn
Institution: University of Michigan
Key Personnel:
Jichun Zhang, U-M grad student
Michelle Thomsen, LANL

Intense Storms vs. Moderate Storms @ Solar Maximum



Comparison

Similarities

- **A geomagnetic storm is driven by sufficiently intense and long-lasting southward IMF [*Gonzalez et al.,* 1994].**
- **During geomagnetic storms, the density of hot ions at geosynchronous orbit vary with time and local time, peaking near dawn side near Dst^*_{min}**
- **The temperature of hot-ions at geosynchronous orbit vary with time and local time, with a minimum in the dawn/noon sector.**

Differences

- **Intense Storms with average Dst^*_{min}= -169 nT are driven by B_z < -10nT lasting for >3 hrs; moderate storms with average Dst^*_{min}= -67 nT are driven by B_z < -5nT lasting for >2 hrs.**
- **At solar maximum, hot ions at geosynchronous orbit are denser during intense storms than during moderate storms.**
- **At solar maximum, hot ions at geosynchronous orbit are hotter during moderate storms than during intense storms, especially around dusk.**

Punchline: Storm intensity increases because of...

- **A stronger convective flow (deeper injection)**
- **A denser plasma sheet (more source particles)**
- **A colder plasma sheet (less B-drift, deeper injection)**